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A Study using a high-addressability Inkjet Proofer to produce amhalftone p roofs matching Kodak approval in color, screening, and subject moiré

Arvind S. Karthikeyan

A Study Using a High-Addressability Inkjet Proofer to Produce AM Halftone Proofs Matching Kodak Approval in Color, Screening, and Subject Moiré

Arvind S. Karthikeyan

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Primary Thesis Advisor: Professor Scott William
Secondary Thesis Advisor: Professor Franz Sigg
Graduate Thesis Coordinator: Professor Twyla Cummings

School of Print Media
Rochester Institute of Technology
Rochester, New York

Certificate of Approval

A Study Using a High-Addressability Inkjet Proofer to Produce AM Halftone P roofs Matching Kodak Approval in Color, Screening, and Subject Moiré

This is to certify that the Master's Thesis of

Arvind S Karthikeyan

has been approved by the Thesis Committee as satisfactory
for the thesis requirement for the Master of Science degree
at the convocation of

June 2009

Thesis Committee:

Scott Williams
Primary Thesis Advisor

Franz Sigg
Secondary Thesis Advisor

Twyla Cummings
Graduate Thesis Coordinator

Twyla Cummings
Graduate Program Coordinator

Pat Sorce
Chair, SPM

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Abstract

An investigation of the feasibility of using a high-addressability inkjet printer as an alternative to the traditional proofing systems, such as Kodak Approval, was completed. The inkjet proofs must match the press sheet in terms of color, screening, screen angle, screen ruling, and screen dot size. The relatively low cost per print and the ability to incorporate color management makes inkjet technology a potential candidate also for use as a proofer for these requirements.

Existing software and patents on halftone inkjet proofing were analyzed. A test form was designed to test the proofing models for screening, screen angle, and screen ruling observed in the proofs. Several workflow models were developed to generate proofs that matched the press sheet in color and moiré. Solutions for the encountered problems were tested until, finally, an optimized model was obtained that was capable of generating halftone inkjet proofs matching the press sheet visually in terms of color and moiré.

This model is simple, cost effective and does not require any special software. However it is limited by the constraints of file size of Photoshop.

Chapter 1

Introduction

The Graphic Communications Association, in its publication GRACoL (General Requirements for Applications in Commercial Offset Lithography), has defined a color proof as a communication and quality control tool that simulates the color and print characteristics to the artist, production staff, and client before the actual print run (Joss, 1999). Inkjet technology has grown to become an integral part of the graphic arts industry especially in the proofing sector. PIRA International (Pira) attributes this growth in the use of inkjet technology to technical improvements in the areas of print quality, cost performance, and product functionality (Kapel, 2005).

With color management, inkjet technology has been able to produce proofs matching the color of the press sheet. Until recently, the halftone rosette pattern produced by a traditional film-based proofers was the only characteristic that inkjet technology could not reproduce. With the advent of halftone inkjet proofing, some proofing solution providers claim high-end inkjet printers could be used to produce proofs matching the press sheet in color, screening, screen angle, screen ruling, and screen dot size (EFI, 2007a).

Halftone inkjet proofing technology has the potential to pose stiff competition for conventional proofing methods. A comparison between inkjet proofs produced with color-managed dot-for-dot reproduction and with proofs from Kodak Approval was proposed. The researcher focused on developing a model for producing half-tone inkjet proofs and testing halftone inkjet technology for the following:

- Color consistency when matching a press sheet
- Reproduction of the screening, screen angle, screen ruling of the press sheet
- Quality of the proofs when compared with proofs from Kodak Approval

The researcher believes that inkjet has the potential to compete with if not replace Kodak Approval. The researcher believes that inkjet technology with the latest developments in addressability and color gamut are capable of simulating press artifacts and moiré. If used effectively, inkjet could prove to be a cost effective solution for halftone proofing.

Chapter 2

Literature Review

It is very expensive and time-consuming to show a hardcopy proof to a customer before printing, using the normal printing process. As such, a proof is needed that simulates printing results accurately, inexpensively, and quickly so that needed corrections can be made in prepress. This need has resulted in the evolution of proofing as an integral part of the prepress operations. Proofing is beneficial as it gives a full color reproduction of the material printed without the cost of running the press. The ideal proof matches the press sheet exactly. This is referred to as WYSIWYG (What You See Is What You Get). Proofing technology ensures a customer could look at a properly made proof and approve it (Hunt, 2004). Proofing is advantageous as it allows for a consistent tonal reproduction once the workflows are set up properly. This ensures that the proofs are color consistent over time (Livens, 2002).

The very first parameter to consider when proofing using inkjet technology is the color match. With color management, it has been proven that it is possible to achieve most of the colors printed with process inks in an offset press (EFI, 2007b). The gamut of the inkjet printer used for proofing is significantly larger than that of the press and helps match the press sheet closely (Hamilton, 2004).

For a proof to match the press sheet in terms of screening, the proofer must match three imaging frequencies of the press sheet (or be proportional). The frequencies in question are:

1. Addressability of the Output Device

   Addressability is defined as the number of spots per unit length. Spots per inch (spi) or spots per centimeter (spc) are the units used to quantify or measure addressability. The use of dots per inch (spi) is incorrect as dots refer to halftone dots rather than to addressability spots (Sigg, 1999). Ideally, the addressability of the proofing device equals that of the press so the proofer can create halftone dots by placing spots the same way as is done by the RIP used for platemaking for the press.

2. Screening Model

   This will include screening frequency, the screen angles chosen, and the bit depth of the dots resulting after the screening. The way the digital file is screened for the proofer is dependent on the proofer and should be optimized to closely match the press sheet (Kipphan, 2001, pp. 566).

3. Repeating Patterns of Image Detail Contained in the Original

   Repeating patterns of image detail contained in the original, include fabric weave, stripes on a garment, or the lattice of a fence. Such patterns can interfere with the dot pattern of the halftones and may cause moirés; also called "subject moiré".

The cumulative effect of these frequencies has the potential of producing moirés in a press sheet. When two frequencies of nearly the same period are superimposed, moiré patterns are most likely to occur. Moiré patterns are most visible in large areas with a repeating pattern or design (Yule, 1967).

Kodak Approval has the same or very similar high addressability as the one used for platemaking (2400 spi or 2540 spi). Therefore, the halftone patterns generated by Kodak Approval are essentially identical to the ones the computer-to-plate (CtP) system generates. Kodak Approval's NX system is designed to proof identical data destined for CtP or press. This ensures that the moiré patterns are simulated faithfully (Eastman Kodak Company, 2008a).

Proofing Substrates

The substrate that could be used for proofing depends on the proofing device. Kodak Approval is capable of proofing on the same substrate that is used for the press (Kodak, 1998). Approval and other film-based proofers use the press sheet for proofing whereas the inkjet printer demands specially coated paper with the top surface treated to retain the colorant (toner or pigment). Inkjet manufacturers and paper mills have developed a wide range of inkjet media to match press sheets. Some of this inkjet media match the CIELAB specifications of paper as described in ISO 12647-7 and are certified by SWOP and GRACoL (Chromaticity, 2008).

Proofer Types

Considering the technology used, proofing systems can be classified into four major categories: Overlay, Laminates, Inkjet and Softproofing.

Overlay

In this analogue method, proofs for each halftone separation are made on a separate film which then are mounted on a substrate. When assembled together, the proof separations have a small layer of air between them which causes internal reflections that desaturate the colors. Hence, they differ from the laminate types described next. 3M Colorkey, 3M Matchkey, and Kodak Accord, are examples of proofers using the overlay method of proofing (Hunt, 2004). These systems are largely historical and no longer used today.

Laminates

In this method, each of the separations is imaged on a special proofing film. These films are then laminated to a special substrate, to which a protective laminate may be added to complete the proof. DuPont Chromalin, Imation Matchprint, Fuji ColorArt, Kodak Signature, Kodak Contract, and Kodak Approval are all examples of systems using the Laminate method for proofing. Kodak Approval is a digital system that uses dye sublimation to create the colors.

Inkjet

Inkjets are becoming the preferred method to make digital proofs due to their high quality, acceptable speed, and price. Inkjets used for proofing are mostly print on-demand inkjets with very high addressability (2880 spi x 1440 spi) (Epson, 2002). The color gamut of an inkjet print is larger than that of most printing presses. The color gamut of printing devices is very important as the printer must be able to proof all the process color combinations the press can print (Core, 2004).

Softproofing

One of the latest advancements in the confluence of computers and the print industry is softproofing. Softproofing involves the use of calibrated and capable monitors to accurately display proofs. Softproofing allows the display of the proofs on calibrated monitors at remote locations (Karthikeyan, 2007). However, monitors have a much lower addressability than printing devices. They compensate for this by having a large bit depth and therefore they reproduce images as continuous tone and not as halftones. Therefore, monitors will not be able to reproduce subject moirés.

Proofing with halftone dots

Colorkey, Chromalin, Matchkey, Art Pro were proofing systems in the analog age that were capable of proofing with halftone dots using the same film used in plate making. In the digital age, Kodak Approval was the first system capable of producing halftone proofs. Kodak Approval was introduced in the early 1990s (Eastman Kodak Company, 2008b). In the case of inkjet printers, addressability was the major limitation for use in the proofing industry. It was not until the late 1990s that inkjet printers were developed with the capability of achieving 1200/1440 spi addressability. An addressability of at least 1200/1440 spi is required to produce a halftone inkjet proof. So it is safe to assume that halftone inkjet proofing had its origins in the late 1990s.

Proofing Requirements

Proofs must satisfy certain parameters before presenting them to the customer. Important considerations are:

1. Color Accuracy and Repeatability

   The accuracy with which the proofer produces the proof is critical as the approved proof is what the press operator strives to match (contract proof). In addition, the proofing device must be repeatable, with consistent proofs provided over time (Livens, 2002).

2. Certification to a Standard

   It is valuable to authenticate each proof, ensuring it meets some standard. Meeting one of the proofing standards such as ISO 12647-7, will give more credibility to the proof (Summers, 2007).

Halftone Inkjet Proofing

Halftone inkjet proofing has its own niche in the area of inkjet proofing. Most of the print houses that have adopted inkjet-based proofing prefer continuous tone prints to halftone inkjet proofs. Halftone inkjet proofs can only be created using commercially available software packages (Ludtke, 2004). In addition, they are difficult to set up and monitor.

The technology used in generating halftone inkjet proofs is based on a number of patents filed in this area. The premise of these patents is that screened separations made for platemaking are used in the proofing workflow. Each dot in the separation is then adjusted for size variations (dot gain the user specifies); color-managed (based on the reference and the profile of the inkjet printer); and mapped as bitmap or as any other file format (Dewitte & Plettinck, 2006).

The Dewitte and Plettinck patent describes a variety of situations with different output devices and color components. The methodology adopted could be summarized as one where the digital file is screened and a Look Up Table (LUT) is used to convert the color values from the original color components to that of the proofing device. After this stage, patented technology is used to convert the resulting file to a continuous tone (contone) file. The continuous tone file is then re-screened at the proofer resolution for output.

The workflow diagram in Figure 1 describes the methodology presented in this patent. Throughout this patent, the term, resolution is used in place of the more accurate term, addressability.

RES 1, 2, and 3 in Figure 1 refer to the resolutions of the printer (output device), the proofer, and the input digital image to be printed. It is also assumed at least one of the proofer color components (M) differs from the printer color components (N). The following list summarizes the proposed workflow:

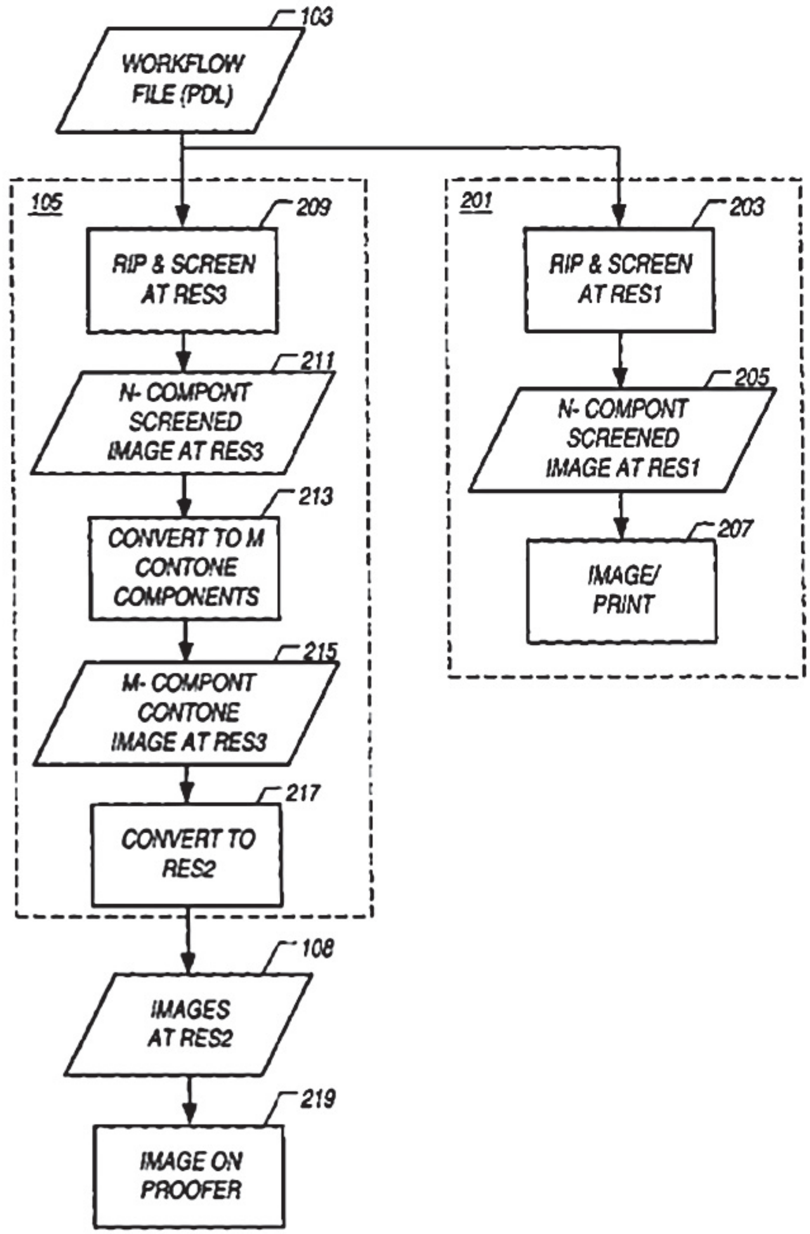


Figure 1: Workflow of Halftone Inkjet Proofing Model, US Patent No. 7068391.

- The input digital image is screened at RES 3 (resolution of the digital contone file) and has N primary color components (color channels making up the entire image).

• The patent talks of a model to use a LUT (Look Up Table) to convert the color values of the screened dots from N components to M components.

• Patented technology converts the resulting The contone image is RIPped at RES 2, which is the resolution (addressability) of the proofer.

• The resulting image is proofed on the proofer.

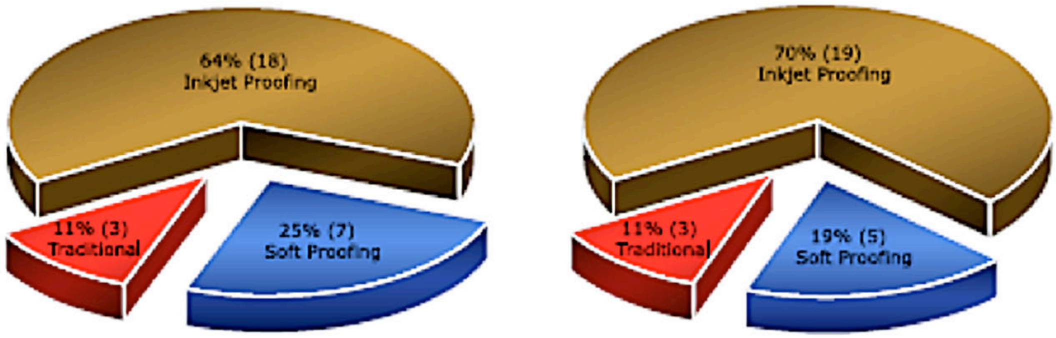
IPA Proofing RoundUP 2006 and 2007 Results

IPA Proofing RoundUP, a part of the IPA technical conference, provides graphic solutions providers with a comprehensive understanding of available color-proofing options and identifies key issues affecting color proofing. For the year 2006, 64% of the proofs submitted were proofed using inkjet technology. In 2007, this had increased to 70%. These numbers are based on the number of entries that were submitted to the IPA Proofing RoundUP. In 2006, 28 vendors and in 2007, 23 vendors and 59 end users participated in this event. Proofs submitted were tested for:

1. Visual match to the press sheet;
2. Colorimetric match (ΔE);
3. Ability to proof multi-channel images;
4. Ability to match Pantone spot colors; and,
5. Cost and other comparators.

IPA Proofing RoundUP saw most of the inkjet-based proofs pass all the above-mentioned tests. This indicates the trend favors inkjet-proofing (Sharma, Collins, Cheydleur, & Smiley, 2006).

Considering the results of IPA RoundUP 2006 and 2007 in Figure 2, clearly the printing industry is gravitating towards inkjets for its proofing needs. The major factor influencing this shift is cost. Inkjet technology has reached a stage



2006 2007

Figure 2: Proofs Submitted at IPA 2006 and 2007 IPA Proofing RoundUP

where it poses a threat to the conventional models of proofing (Collins, Eddington, Habekost, Levine, Sharma, & Smiley, 2007).

Chapter 3

Objectives and Research Questions

Objectives

A model was proposed for using inkjet technology for producing proofs matching Kodak Approval proofs in terms of color and screening. In addition, a comparison of the results produced by commercially available halftone inkjet proofing software and the model developed by the researcher was also proposed.

Research Questions

The following four research questions were addressed:

1. Can halftone inkjet proofing match the screen angle, screen ruling, and screen dot size of the press sheet even though it has a different addressability than the Computer-to-Plate (CtP) imagesetter used for an offset production press?
2. Can halftone inkjet proofing match the press sheet for color consistently within tolerable limits when also matching the screening?
3. Are the proofs that halftone inkjet technology produces of comparable quality to that of Kodak Approval? Does the inkjet proof match the colors of Approval proof visually and quantitatively?
4. How do the proofs produced by the proposed model compare with those of commercially available proofing solutions?

Limitations:

Only screening of 150 lpi was tested, as this has been one of the more commonly used screening frequencies used for offset printing. Inkjet proofers currently have a lower addressability (1440 spi) than offset plates (2400 spi). Therefore the finest screen ruling that an inkjet device can print is also coarser than the one that an offset press can print. A screen ruling of 150 lpi is just about the highest that can be imaged at 1440 spi without visible shortcomings, but still high enough to represent work done for publication printing. If higher screening frequencies are used the number of gray levels that the inkjet printer can achieve are reduced, making it very difficult to simulate 256 gray levels. Only CMYK color space was tested, spot colors were not tested.

Chapter 4

Development of a Methodology

The researcher investigated various proofing methods using an inkjet printer, attempting to produce proofs matching Kodak Approval (or the press sheet) in terms of moiré, screening, and color. Kodak Approval simulates an offset print very closely, including subject moiré, when the same RIP is used for both proofing and platemaking. Therefore, a Kodak Approval proof was used as the point of reference for this study. A test form was designed for this research and the materials and equipment to be used were chosen and calibrated. ICC profiles were created for all the devices used in this research. Workflows (models) were developed to use the inkjet printer and match the press sheet in terms of color and moiré.

Materials, Equipment and Software

The main requirement of the inkjet printer to be used was that the addressability is as high as possible. An Epson Stylus Pro 4000 inkjet printer with an addressability of 2880*1440 dpi was used. The paper that has to be used for the test run is very critical. The color of the paper has to very close to that of the press. It is also important to consider the amount of Optical Brightening Agent (OBA) in paper. OBA is an additive added to paper that absorbs light in the Ultra-Violet region of the spectrum and reflects it in the blue end of the visible spectrum, thereby giving the paper a brighter appearance. The amount of OBA will play a major role in metamerism, where the printed image will look different when viewed in different lighting conditions. To reduce the effect of metamerism due to paper, inkjet paper manufactured without OBA was used for this research. Epson Proofing Paper Semi-matte was used throughout this research.

Profiling Approval and the Inkjet Printer

Kodak Approval and the inkjet device had to be profiled to create ICC profiles used in color management. Profiling involves printing a target such as the IT8 7.4 on a calibrated device and measuring the printed colors. The instruments used for measuring the printed IT8 target were X-Rite i1-iSiS and SpectroScan. Profiling software used was X-Rite/GretagMacbeth, ProfileMaker, and X-Rite MonacoProfiler. Default settings for ProfileMaker that were used include, Paper Colored Gray in the perceptual rendering intent type, D50 as the viewing light source, and LOGO classic gamut mapping were used to create the output profile.

The inkjet printers used in this research were Epson Stylus Pro 4000 and 9800. Both these printers are capable of printing at 1440 spi. ICC profiles supplied by the inkjet manufacturer were used along with profiles created by printing profiling test forms without any color management (legacy settings). The ICC profiles were created with the same settings as that of the Approval profile.

Kodak Approval Settings

A test page was created with the IT8 target for proofing on Approval. The color management settings in Adobe InDesign were turned off. The workflow that was used for making this proof on Approval was the one used to make the proofs conforming to SWOP standards to imitate press performance. The screen angles and frequency were set according to the specifications of SWOP with screen angles set to Cyan at 15°, Magenta at 75°, Yellow at 90°, and Black at 45° and the screen frequency was set at 150 lpi. Also in the screening settings, Harlequin Precision Screening (HPS) was used to specify the tolerances for the screening.

Development of the Test Form

A test form was designed to check for the proofing device's ability to match the press sheet. It includes images known to cause moirés with the screening. Test targets included in this test form indicate screen angle, screen frequency, and dot gain. These parameters were checked after an acceptable color match was achieved.

The use of a modified Screen Pattern Analyzer for Proofs and the Contrast-Resolution Target serve as indicators of the screening properties of the proofing device. The test targets shown in Figure 3 were made separately for each of the process colors. The use of a halftone tint as a background for the Screen Pattern

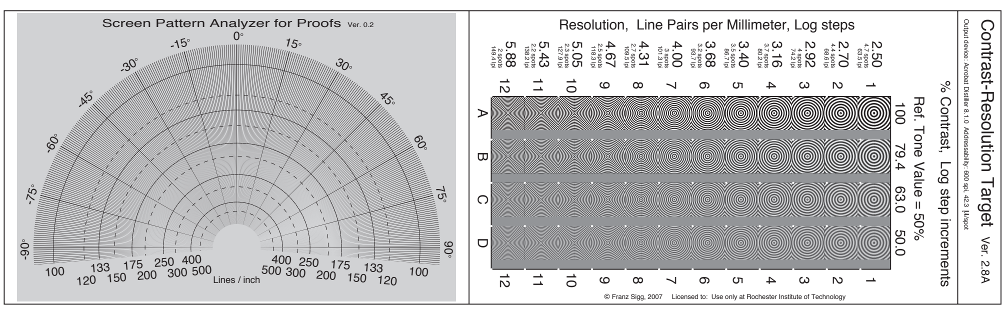


Figure 3: Contrast- Resolution Target

Analyzer target results in a moiré indicating screen angle and screen ruling. The lines of these targets may also be thought of as a representation of image detail making a moiré with the screening. If the halftone inkjet proofing model is successful, then the moirés formed in these targets should be the same as those for the Kodak Approval print.

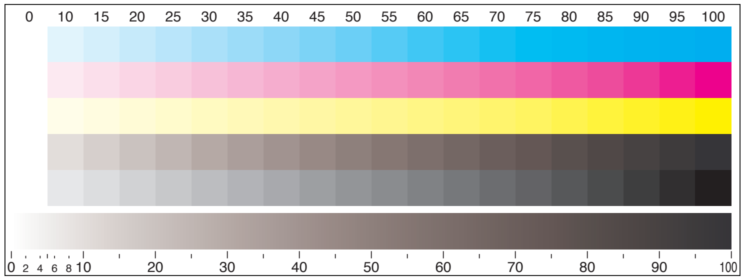


Figure 4: Step Wedge

The step wedge, shown in Figure 4, was designed to have wedges of Cyan, Magenta, Yellow, Black, and 3-color Gray. The step wedges are in steps of 10% dot area and are clearly demarcated. There is also a 3-color gradient.

Step wedges serve as visual and measurable indicators of tone reproduction and the purity of the colors reproduced. As they include solid patches (100% patches), they could be used to measure printing density.

Pictorial test images were included to qualitatively show color match and print quality with reference to a standard. This test form includes standard images such as ‘The Three Musicians’ (N7A) (Figure 5) and the neutral N4A image (Figure 6).

Since one of the primary objectives of using this test form was to check for the reproduction of subject moirés, images known to produce subject moirés on press

Figure 5: Three Musicians

Figure 6: Neutral Test Image

Figure 7: Images with Moirés

were included in the test form. The image of a Bose® speaker (Figure 7) has a history of moiré problems associated with it when using AM (Amplitude Modulated) screening (Wecht, 2007). A test image with Franz Sigg and the researcher wearing striped shirts and holding a book with a screening pattern in the cover was also included as a test for moirés. The moiré produced is dependent on the magnification of these images. An Approval proof was made with varying magnifications of these images and the magnification percentages that showed pronounced moirés were chosen.

This test form will qualitatively and quantitatively illustrate the difference between the screening in the proof and the press sheet.

Halftone Inkjet Proofing Models

The workflow diagrams shown in this section describe the steps involved in each of the halftone inkjet proofing models in comparison to a press workflow. The patented model of Dewitte and Plettinck is first described.

Control Workflow

The workflows of Figure 8 were included as references against which the models proposed in this research were compared. The platemaking workflow was the first reference against which all the workflows were compared. No printing was actually done, instead a Kodak Approval Proof represented performance of a standardized press setup. Figure 8 shows the workflows of the hypothetical press and of the Dewitte and Plettinck patent.

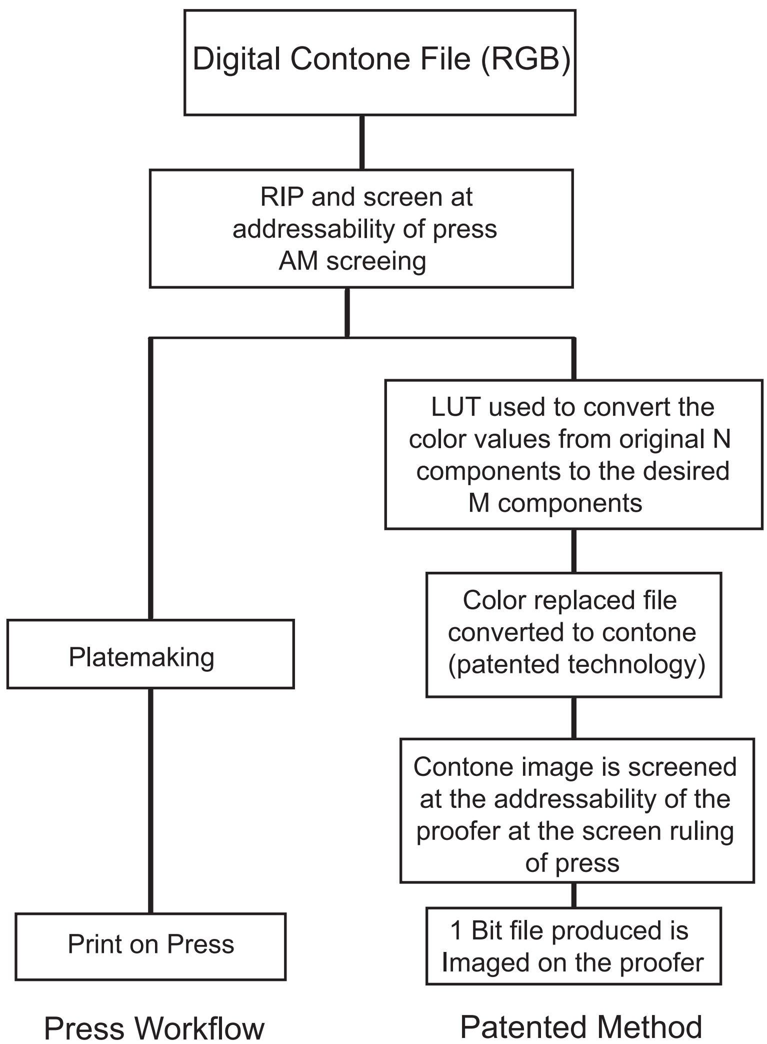


Figure 8: Press and Patented Workflows

Press Workflow

Screening and profile conversion take place in the RIP for CtP.

Dewitte and Plettinck Model

The model described in the patent is one where the ripped file from CtP is also used for the starting point of the proof. The separations are screened 1-bit files. These files cannot be used directly for inkjet proofing as inkjet has a different addressability and uses more than four colors. Therefore, the methodology of the patent is to process the 1-bit files separately and to use a Look Up Table (LUT) to convert the color from the original color components (color separations, often CMYK) to the number of color components of the proofing device (for inkjet this is often more than four colors). The Dewitte and Plettinck model involves conversion of these screened 1-bit files to continuous tone. The contone files are then screened at the same screen ruling that is used for the press and at the addressability of the proofing device. The screened 1-bit files are proofed on the inkjet printer.

Stages in the Development of the Methodology

After analyzing the patent, five custom models were defined and tested, each one addressing problems of the previous one.

Model 1

Model 1 was the starting point for a series of experiments that were eventually done. The idea was to use the same 1-bit halftone separation files that the RIP generated for the press workflow as input to the inkjet proofing workflow. This would have the advantage that the identical screening would be used for both press and proof. This then would guarantee that the same moirés would result in both prints. Therefore the task for Model 1 was to color manage these 1-bit separation files so that the color rendering on the proof would look the same as on the press. Figure 9 shows the workflow steps of Model 1. It is not possible to apply normal color profiles to 1-bit files, because normal color profiles are designed to change the tone values of the image. And a 1-bit file has only two tone values: 100% area and 0% area, and nothing in between. The only way to color manage a 1-bit file would be to change the dot areas of the halftone dots in that file. But this cannot be done with a normal color profile.

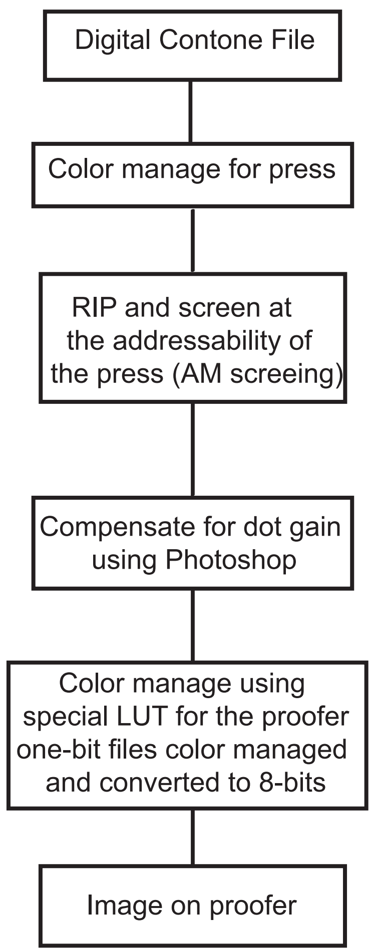


Figure 9: Model 1 Workflow

However, if the colors of the halftone dots (and solid areas) of the proof were the same as on the press sheet, AND, if the dot areas on the proof and the press sheet were also the same, then no color management is needed. So the question is, how to simulate the press dot gain on the proof, and, how to make the inkjet primary colors have the same colorimetric values as the ones on the press sheet.

Dot gain: It was planned to use the Expand function in Photoshop to increase the dot areas of the original 1-bit files in order to simulate the dot gain of the press. The following sequence of commands can be used: convert each 1-bit separation file to Grayscale which makes it an 8-bit file that has only 0% and 100% tone values. Use the Magic Wand to select all black areas by clicking in the middle of a dot or solid area (Unclick the contiguous button). Then, Select > Modify > Expand by one pixel. Then use the Paint Bucket tool to fill the selection with black. Deselect. Now all dots are bigger because they have an additional border of 1 pixel. Save the file with a new name. The amount of tone value increase can be verified by temporarily blurring the image until the dot structure is lost, and then use the Eye dropper tool to measure the new tone value. If this is done with an image of a step wedge, and the before and after tone values are plotted in a graph, a bell shaped curve is obtained. This is so because small halftone dots have a much smaller periphery than a 50% dot, and therefore less area is added to the small dots.

Color correction: The colors of the inkjet proof of the dots and solid areas could be matched to the press by using a normal CMYK to CMYK profile as is customarily done in proofing applications. Because the 1-bit file only contains solids and no tints (the dots are also small solid areas), this color management would only affect the solid areas of the proof. For this to work, the 1-bit file would have to be converted to 8 bits, otherwise the profile cannot be applied. This 8-bit file also only contains solids and clear areas, no other tints. This would fulfill the first requirement. So, we would take each 1-bit separation, convert it to 8 bits, recombine those 4 separations in Photoshop to make a single composite CMYK file. Now we could assign the press profile and then convert to the proofer profile.

Now all the dots would have the same color as the press sheet has, and the same dot areas. Therefore the inkjet proof should match the colors of the press print and also possible moirés.

Note: This approach to make a dot proof is similar to the way that an Approval proof matches a press proof. For Approval, the sublimation dyes are carefully chosen to match the hue and saturation of the color of a press print, and exposure adjustment in Approval adjusts the color strength, similar to an ink film thickness adjustment on a press. Once the solid color is a good match, then a three dimensional color management (ICC color profiles) is no longer needed, one dimensional transfer curves are sufficient to obtain a match of tone reproduction.

Results of Model 1

There are some residual errors with Model 1:

1. On a press sheet, dots do not have the same uniform color as a solid would. Press dots have a fringe, which has a different ink film thickness and therefore a different color. This model does not simulate this.

2. The dot gain curve obtained by adding a constant border around the dots does not exactly match the dot gain curve on a press. But it might be close enough to result in a visually acceptable match.

Model 1 was not implemented because dot gain is not easily controllable when using the Expand function of Photoshop. Changing dot areas can only be done in steps of 1 pixel. How much of an area change this is, is a function of the addressability and screen ruling (and dot shape). For instance, adding one pixel around each dot for a 150 lpi halftone screen at 2400 spi causes a mid tone dot gain of 17%, while doing this at 1440 spi causes a mid tone dot gain of 26%. If this value is not what is required, then the next larger value, which is obtained by adding two pixels, is much more, too much more. A solution to this problem would be to first change the Resolution of the file in Photoshop. However, this greatly affects file size to the point where the file may no longer be able to be processed by Photoshop because it is too big.

Solutions for problems with Model 1

The problems with Method 1 stem from the fact that there is no easy way to apply color management to a 1-bit file. Therefore the assumption was made that the user would have access to the contone file of the form to be printed. The methods developed to include color management in the contone file are discussed below.

InDesign and Color management

The test forms for this research were designed using Adobe InDesign CS3. The researcher had problems with the color management of this test file made of images and vector test targets. Color management settings in InDesign were specified with absolute colorimetry. When InDesign was asked to color manage a test page with both bitmap and vector images, the white background of vector files was not color managed with absolute rendering while bitmaps were correctly rendered.

To circumvent this problem: instead of applying color management in InDesign, color management was applied to the PDF file saved out of InDesign, using

Adobe Acrobat. The individual test elements were placed in the InDesign file. A PDF file of the test page was generated from InDesign. The PDF file was then converted to the profile of the press using Adobe Acrobat. Absolute rendering intent was chosen when paper white had to be simulated. In addition, the file can also be converted to the profile of the inkjet printer. Thus the file was color managed for both the press and the inkjet printer. This method was used to color manage the white background of a vector file.

Model 2

Model 2 makes use of the contone-based color management workflow using Adobe Acrobat. The color managed contone file was RIPped at the addressability of the press to evaluate the print quality when a 2400 spi file is printed on an inkjet printer. Though the addressability of the inkjet printer is 1440 spi, it can print 2880 spi along the horizontal axis. The result of printing a 2400x2400 spi file using an inkjet printer of 2880x1440 spi was tested in this model. Figure 10 shows the workflow of Model 2.

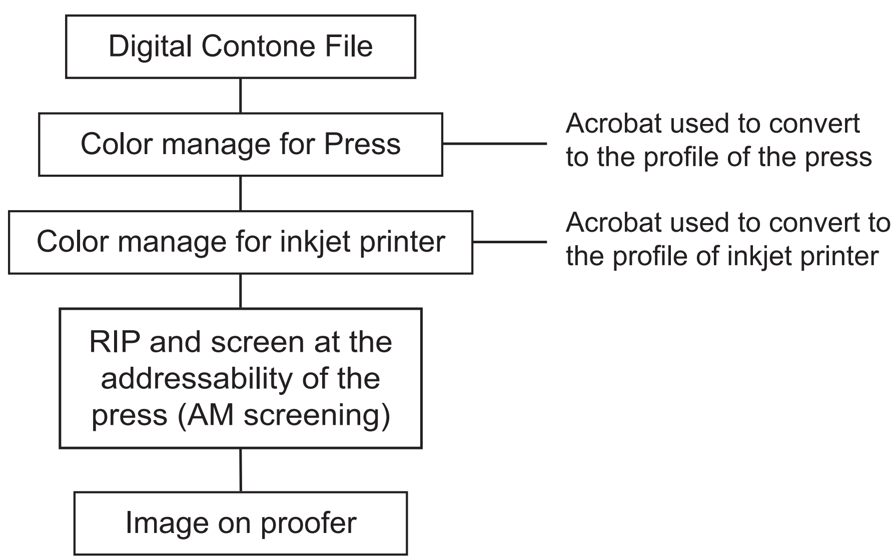


Figure 10: Model 2 Workflow

As the contone file had been color managed for the press and the inkjet printer, the color variations that arise as a result of dot gain have been compensated. This method solved the color management problems, but new problems became apparent:

Problems with Model 2

1. It was thought that the proofs had to be generated using process colors only, in other words, the light colors of the inkjet printer had to be turned off. This required a special RIP. However it was found that this RIP was only capable to either turn off the light colors, or print the 1-bit separations without the need to recombine them first in Photoshop.

If the files were combined in Photoshop, the size of the resultant file was too big. In many cases the file was beyond the maximum size of the image that Photoshop could handle.

When the light colors are turned off, the images lacked detail in the highlight regions.

2. There were unacceptable moirés (artifacts) visible in the gradients. Approval proofs had no moirés in the gradients.

Solutions for the Problems with Model 2

The problems with Model 2 required an investigation of the setting of the number of colors used by the inkjet printer, and optimizing the RIP settings to reduce the moirés caused by the different addressabilities of press and inkjet proof.

Setting the number of colors. At the beginning of the research it was believed that the main criterion to be considered when setting up the RIP for the inkjet printer was the number of colors in the inkjet printer. The number of colors selected are used by the RIP to process the image. The primary criterion in the selection of the inkjet printer is the addressability of the device. But most of the high-addressability inkjet devices have more than four colors and hence, have to be used by limiting them to the four process colors. This limiting of colors cannot be done in the printer driver interface. However, some external RIPs allow the user to turn off the extra colors in the inkjet printer and therefore it is necessary to use such a RIP and a high-addressability inkjet printer combination.

It was assumed initially that for an inkjet printer with eight colors, the halftone rosette pattern produced by the different screen angles will be totally different when compared to that of Approval, which uses only four process colors. In the case of the 8-color Epson Stylus Pro 4000, the colors are Cyan, Magenta, Yellow, Black, light Magenta, light Cyan, light Black, and light Black. The light colors are used to print the highlight regions of the image. The size of the dots used to simulate these highlight regions are larger but produce the same visual response as that of a press sheet. It was assumed that this change in dot size was undesirable as it might affect the moiré pattern and hence, to simulate Approval proofs, we need an inkjet that uses only four process colors. However, after making test prints with four and with eight colors, it was found that both had moiré patterns that were visually similar. The lighter colors were printed with the screening and screen angle of the corresponding CMYK primary. The resultant moiré pattern did not change because of the presence of lighter colors. Therefore, in the subsequent models, the combined 1-bit files were printed, not using an external RIP, but directly through the Epson printer driver (using all eight colors, and with all color management turned off). This has the advantage that the light image colors are also reproduced, not just the dark ones.

Binary AM Halftone Inkjet Proofs. The observed moirés in the gradients required a closer look at the screening setup. Inkjet printers normally print with a screening that approaches continuous tone. However, the halftone proofs made must be of the same screening as the press (represented by Kodak Approval proof), which is 150 lpi AM screening. The Epson 4000 printer used to proof the test form has a fairly high addressability of 1440 spi, which is high enough to obtain a screen ruling of 150 lpi. One difference between the print produced with Kodak Approval and the proof using inkjet technology was the addressability of the output device. Kodak Approval produces proofs at 2400 spi, whereas inkjet images at 1440 spi. Although both systems are capable of producing a 150 lpi halftone, the spot pattern producing the individual halftone dots was different for the two systems and therefore the proof has to be ripped at 1440 spi, not at 2400 spi, to avoid moirés.

RIPs have the ability to optimize the screening for the desired addressability. The screen ruling chosen by the RIP may be slightly different from the desired ruling to minimize possible moirés between the addressability grid and the screening frequency. This was not desired in this application, as it was important to produce the same moiré pattern in the proof and the press sheet. Hence it was imperative to turn off this option for the proofing RIP. This way, the major moirés will be the same for both Approval and inkjet proof between the screen ruling and the subject detail.

Optimized RIP settings

The Harlequin RIP that drives Approval at 2400 spi was also used to generate the screened 1-bit files that were used by the inkjet printer, but using an addressability setting of 1440 spi.

Approval is driven by a Harlequin Genesis RIP. The RIP workflow was set to SWOP standard with the screening frequency at 150 lpi with Cyan at 15°, Magenta at 75°, Yellow at 90°, and Black at 45°.

The Approval settings were the ones used by the Digital Publishing Center at RIT and have been used and optimized for optimal performance to simulate the offset press. To achieve accurate screening, the tolerances for the screen frequency and the screen angle can be set in the RIP. The default tolerance for these parameters was set to be ± 7%. This was very high and did not yield accurate screening in the 1-bit files. The Harlequin RIP allows the user to set a tolerance for screening errors. It has been stated in the Harlequin RIP Manual that moiré can be kept minimal if the screening of Black is reduced (in this case from 150 lpi to 144 lpi) and those of Cyan, Magenta, and Yellow are increased (from 150 to 156 lpi) (Global Graphics, 2005). This is a part of the processing that happens inside the Harlequin RIP. The default tolerance of ± 7% explains the 6 lpi adjustments in frequency observed in some cases to minimize moiré. This tolerance value was now set to 1% to force the RIP to use the same screen ruling and screen angles for both sets of separations done at 2400 spi and 1440 spi.

Based on these results a new model was developed working at 1440 spi and introducing color management in the contone file and printing with all the colors available in the inkjet printer.

Model 3

The contone file was color managed for the press and the inkjet printer using Acrobat. The original contone file was converted to the profile of the press-using relative rendering intent (absolute rendering can also be used). Relative rendering was chosen as the CIELAB values of the proofing paper was very close to that of the press sheet. In case there are larger differences in the CIELAB values of the proofing and the press sheets, absolute rendering might be used. Figure 11 shows the workflow of Model 3.

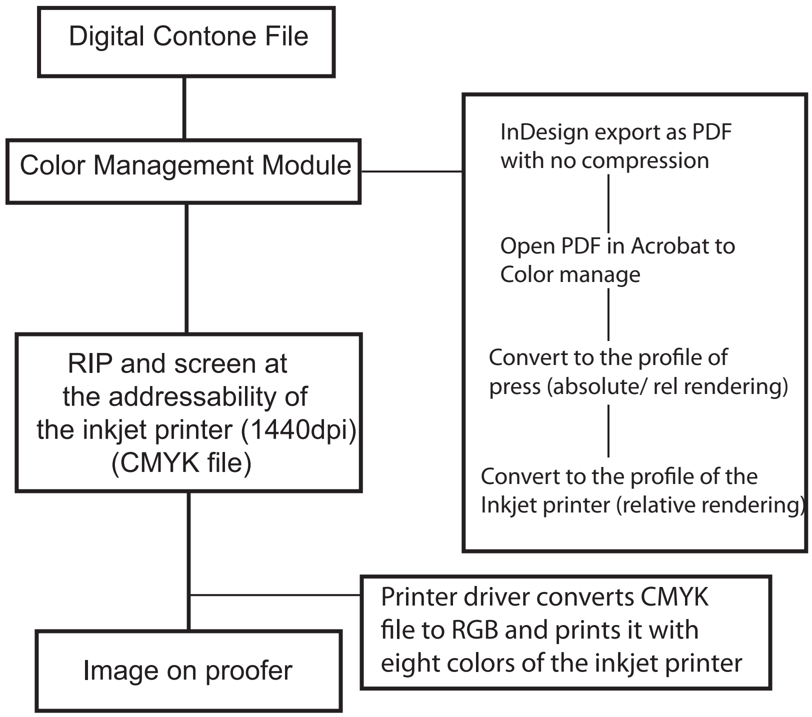


Figure 11: Model 3 Workflow

The contone file was then color managed for the inkjet printer. The rendering intent was chosen to be relative. Thus the contone file was color managed for the press and the inkjet printer. The file remains a CMYK file in this stage and the profiles used in the color management are CMYK profiles created by the user. However, the Epson inkjet driver internally first converts the incoming CMYK data to RGB, and then converts the RGB channels to all the eight colors of Epson 4000. The driver is the software that converts image data into meaningful data that the inkjet printer can process.

The color management in the contone file is designed to match the proofer response to the color and the dot gain changes that occurs in the press. The RIP was setup to generate 1-bit separations at 1440 spi. The screening parameters such as screen angle, frequency, and screening type were set identical to that of the press workflow. This was to ensure that the 1-bit files match the screening of the plates sent to the press. Thus this system matched most of the factors governing the moiré pattern (screening and image detail). The difference between the files sent to the press and the inkjet printer was the addressability.

Results of Model 3

The proofs generated by this model yielded better results than the previous models. When using Photoshop to print the combined 1-bit separations, the size of the resultant file was less than that of Model 2. In spite of ripping at 1440 spi, there were still patterns (artifacts) observed in the gradients and images.

Solutions for the problems of Model 3

At first, there was a suspicion that the patterns visible in the gradients could be caused by the limited number of available gray levels. Equation 1.0 is used to calculate the number of gray levels for single cell screening at 1440 spi.

$$\begin{aligned}\text{Gray levels} &= (\text{Addressability} / \text{Screen Ruling})^2 + 1 \qquad (1)\\ &= (1440/150)^2 + 1\\ &= (9.6)^2 + 1\\ &= 92.16 + 1\\ &= 93 \text{ Gray levels}\end{aligned}$$

Though the inkjet printer uses less than 256 gray levels, the steps are so small that they cannot be the cause for the observed patterns in the gradients. It was now clear that the patterns are moirés.

Moiré in Gradients. The gradients should appear continuous, however it was found that when contone files ripped at 1440 spi were used as the input, a moiré was clearly visible in the print. This was most pronounced in the gradients and made the proofs unacceptable. Figure 12 illustrates the moiré patterns observed across the test form.

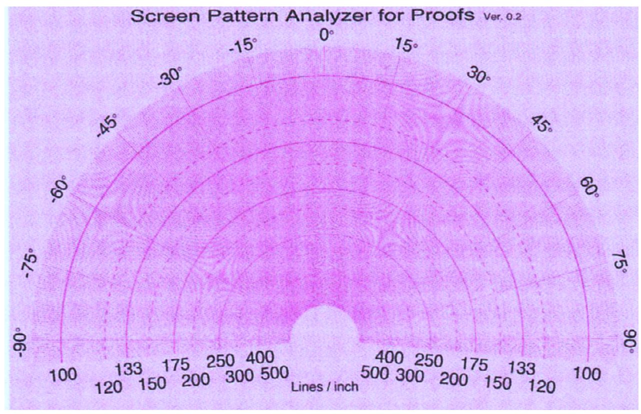


Figure 12: Scanned Print Showing Moiré

As mentioned in the introduction, there are 4 frequencies that potentially can cause moirés: 1. Image detail (causing subject moiré), 2. Image sampling (ppi), 3. Addressability of output device and 4. Screening. The screen angle of the observed moiré was the same for all four colors; hence the moiré in the inkjet proof cannot be attributed to screening. The moiré is not due to subject moiré either, because it is also visible in uniform areas. And it cannot be due to the pixels of the image because it is also visible on vector areas (that are not a bitmap). The moiré could be caused by the addressability grid, but at least two frequencies are needed for a moiré. So, what could be the second frequency, if it is not screening or pixel sampling or subject detail?

The only other frequency that could cause a moiré is the difference in the addressability grid of the file generated by the RIP and the addressability grid of the inkjet printer. Both the RIP and the inkjet were set to operate at a nominal 1440 spi but they could have slightly different addressability grids. Therefore, to test this hypothesis, a small change in image size of the screened reproduction could make both addressabilities the same, which would eliminate the moiré.

It was observed that the Period of the moiré was 4.5 mm. This means that every 4.5 mm, the addressability of the RIP and the printer were different by 1 spot. The following shows the calculation of the size ratio required to eliminate the moiré:

1 inch = 25400 μ

Addressability of the inkjet printer	= 1440 spi
Size of one addressability spot	= 25400 / 1440 = 17.6 μ/spot
Size of the moiré period	= 4.5 mm = 4500 μ
Number of spots in the moiré period	= 4500μ / 17.6μ = 255.68

Therefore, because there is one spot difference per moiré period,
size ratio is either 255.68 / 256.68 = 0.996 OR 256.68 / 255.68 = 1.004

This indicates that the moiré could be corrected by changing the magnification during printing of the test form by a value of 0.4% (the calculation yields only the difference but does not indicate the direction in which the correction has to be effected). In this case, when the test form was printed at 100.4% the moiré patterns disappeared, resulting in a good print. Therefore this proves that the moiré was caused by the slight difference in addressability grid between the RIP and the inkjet printer. These calculations have to be performed for every application to ensure that moiré has been eliminated completely.

Residual moiré. Even though the large moiré was removed by a small adjustment in image size, small (low intensity) moiré patterns were still visible in the 40 to 60% region of the tone scale. They were not noticeable with the larger moiré present.

These moiré patterns had a different moiré angle for every color. Therefore they must be an interference pattern with the screening. They were clearly visible in Magenta, Cyan and to a lesser extent in Black, but were not visible in Yellow. The moiré patterns observed in Magenta and Cyan were symmetrical to the vertical axis and mirror images of each other (the screen angles for Cyan and Magenta are 15˚ and -15˚). Whereas Black shows a moiré at 45˚ angle that is lighter and different from that observed in Magenta and Cyan. These moirés could be a result of the tight tolerance that had to be set in the RIP to make sure that the same screening was used for the proof and the press (1% for screen frequency and angle). By forcing the RIP to use a screen ruling and angle at 1440 spi that it would not otherwise have chosen, a less than optimum choice of screening parameters was applied, and this could be the cause for these minor moirés.

Using blurring of 1-bit separations to remove residual moirés

A method to remove these small moiré patterns can be the application of some blurring in Photoshop. The 1-bit separations were converted from 1-bit to eight bits, and Gaussian blurring was applied. This means that now the halftone dots are no longer sharp, they have soft edges. Although the spots of the RIPed file are mapped in a 1440 spi addressability grid, when the blurred file is sent to the printer, it can use the maximum addressability of the inkjet printer, which is 2880x1440 spi. When the blurring is introduced in the file, the printer renders the separations with a higher addressability. When printing the same patch with and without blurring, the results obtained were very different. The sample printed without blurring showed a clear grainy pattern. The blurred file looked more continuous and the colors were slightly different. Different levels of blurring were tested to find one that still showed the subject moirés but had less graininess.

Figures 13 and 14 represent an enlarged section without and with a 2% Gaussian blur.

It can be observed from the images that the Gaussian Blurring evens out the area and makes the different dot structures print with similar patterns. This will ensure that residual moiré patterns are not pronounced. The amount of Gaussian

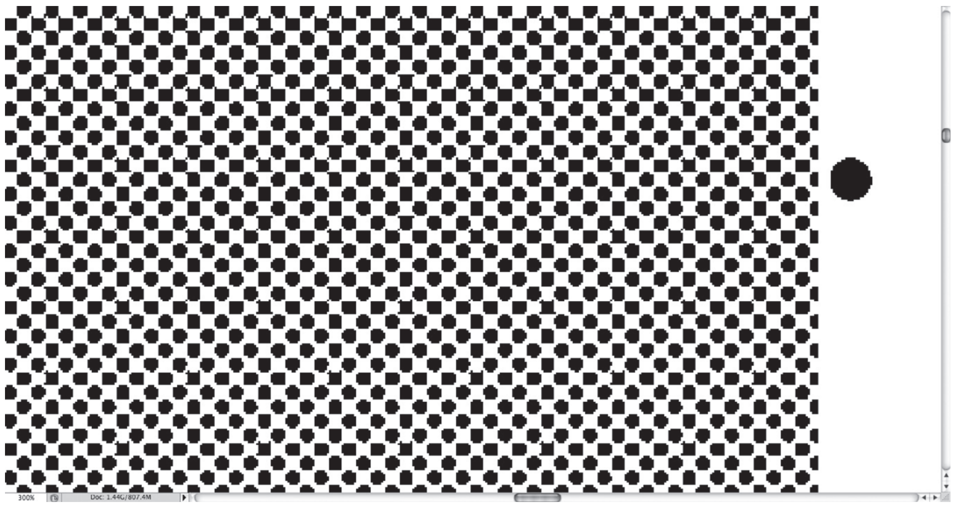


Figure 13: Black separation at 300% - Unblurred

Figure 14: Black separation at 300% - with 2% Gaussian Blur

blur was a factor of the resolution of the file and the addressability of the output device.

The file that was blurred was still a CMYK file made with the 1-bit separations from the RIP. The blurring of the combined 1-bit files solved the problem of residual moirés in the proofs and is used in the subsequent models.

Model 4

Model 4 is very similar to Model 3; expect that the halftone bitmaps were blurred slightly before they were printed. The files were RIPped at 1440 spi.

The original contone file was a CMYK file and remains a CMYK file after it was converted to the profiles of the press and the inkjet printer. The color managed contone file was RIPped at the addressability of the inkjet printer (1440 spi). The 1-bit separations were made into a composite file consisting of the four separations as channels. This file was then converted to Grayscale. This is necessary to apply the Gaussian blurring. The file was no longer a 1-bit composite file and had to be treated as a single file. The file was saved and printed directly from Photoshop.

Printing the combined file directly from Photoshop presented a few problems. The file at this stage was a CMYK file. The inkjet printer with more than four colors and image processing mechanism built inside has to be treated as an RGB device. Photoshop CS4 did not allow the user to print this file without color management. Though it was possible to print this directly using Photoshop CS3, this operation crashed the program frequently. Figure 15 shows the workflow of Model 4. The file was a CMYK file till it was printed.

Results of Model 4

The printing of the blurred file with the inkjet printer presented the biggest problem. The conversion of the blurred CMYK file to the printer space was not accessible to the user. This was a major limitation of this model. When working

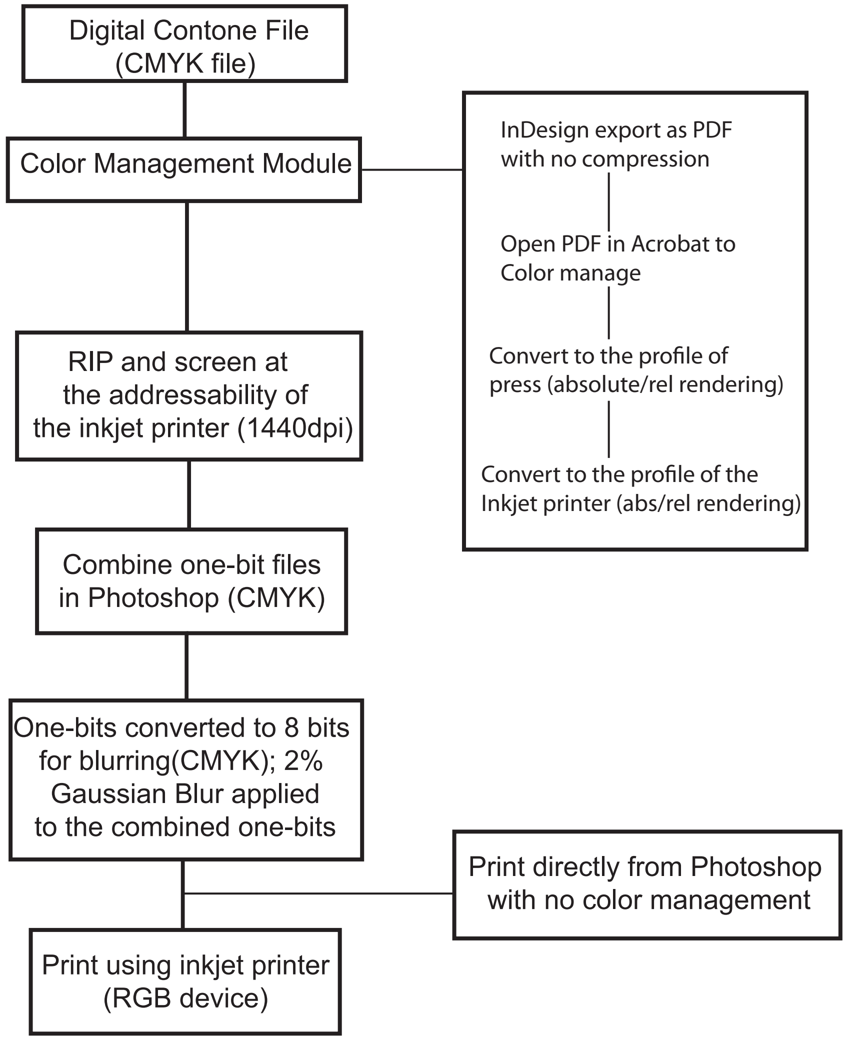


Figure 15: Model 4 Workflow

with CMYK files, Photoshop uses color management at the print dialog to convert the file to the working space of the inkjet printer (RGB). When color management was turned off, the file and the working space of the inkjet printer differ, leading to problems (file - CMYK; printer - RGB).

The other problem observed with this model was that the moiré pattern observed in some of the test images appeared lighter. This was because the color management of the contone file changes the values of the colors in the file that is sent to the RIP. The RIPped separations, when combined, have different color values. As mentioned in the previous model, the blurring step also decreases the contrast of the image content resulting in a lower contrast and made the proof look lighter. Thus color management and the blurring reduced the contrast and sharpness.

Solutions for problems in Model 4

The workflow described in model 4 was set up for printing the file directly from Photoshop. Other methods were also used to print this file. The separations could be printed using a RIP that recognizes the separations or by combining them as a single file in Photoshop. External RIPs were used to make full use of the high resolution of inkjet printers. RIPs available at the Digital Publishing Center (DPC) at RIT were tested and yielded mixed results. The use of external RIP allowed the user to include color management at the RIP interface. The color management interface is different for every RIP. The profile of the press and the inkjet printer was used in the RIP and the proofs matched the reference sheet in terms of color. But as the RIPs do not allow the user to include blurring and other image manipulation, it was not possible to get an exact moiré match. Some basic RIPs (RIPs with limited features) do not recognize the separations and hence required the combined 1-bit separations (a single CMYK file). When 1-bit separations were combined and blurred, the halftone detail was lost and the resulting file was processed like a contone file. Basic RIPs that accept the combined 1-bit file treated the file as a single file and used error diffusion or stochastic screening to print. This stochastic screening overrode the AM screening in the separations and so the halftone pattern was lost. The moiré patterns looked very different and hence this method did not serve as the optimal means to achieve halftone proofs.

This problem was corrected by changing the stage in the workflow where color management was introduced. A test run was prepared with the original con-tone file (no color management), which was then RIPped at 1440 spi. The 1-bit separations were combined and blurred in Photoshop and printed directly to the inkjet printer. This resulted in very similar moiré pattern as that of the press sheet. This validates the claim that the moiré pattern matches the press sheet when files with the same color values are printed. However in this method the colors in the proof did not match the press sheet. Color management had to be introduced without altering the color values of the file sent to the RIP. Hence color management was introduced later in the workflow. It was observed that when the combined 1-bit files were printed from Photoshop, color management could be introduced at the print dialog. Photoshop color management was enabled and a profile supplied by the inkjet manufacturer, for the paper used to proof, was chosen. The profile chosen has to be an RGB profile supplied by the inkjet manufacturer. This is because the Epson Stylus Pro 4000 printer used for proofing has eight colors and inkjet printers with more than four colors have an internal mechanism of processing to print files with all the eight component colors. This mechanism makes the inkjet printer behave like an RGB device. CMYK files when printed have to go through an ICC profile to be converted to the RGB space. These files will then be processed by the printer to print with all the eight colors available.

The gamut of Approval lies within the gamut of the inkjet printer; hence it was sufficient to limit the amount of ink by means of this step. The manufacturer of the printer driver builds these calibration details into the RGB profile supplied with the inkjet printer. If instead of using the print driver profile, a custom CMYK profile were used at this stage, it would not contain the ink limiting included in the manufacturer supplied RGB profile, resulting in a bad color match. Thus it was important at this stage to use an RGB profile for color management. Also when using Photoshop CS4, the software does not allow the user to turn off color management when printing a CMYK file to an RGB printer.

Model 5

Based on all the earlier models and the solutions developed for the problems with them, an optimized Model 5 (Figure 16) was developed. This method uses the original contone file for color management. It was assumed the user has access to the contone files that were used to make the screened files for platemaking. The use of a contone file (without color management) at the RIP ensures that the 1-bit separations are very similar to those sent to platemaking and hence match the moiré pattern accurately. Also when the 1-bit separations are made at 1440 spi, the size of the files and the amount of processing required is less than when using 2400 spi. A 20x26" file at 1440 spi is 4GB in size. The actual size of a press sheet can be much higher than 20x26".

The contone file in this method is RIPped at the addressability of the inkjet printer (1440 spi). The 1-bit separations are combined in Photoshop and then converted to 8 bits. Then they are blurred. After blurring the file is still a CMYK file. This combined file is printed directly from Photoshop to the inkjet printer. An RGB profile is used to color manage for the inkjet printer at the printer driver. As the inkjet printer has more than the four process colors it needs a printer driver that treats the printer as an RGB device and color manages the files before parsing it for all the component colors. The RGB profile used converts the file to Profile Connection Space and then the printer driver then converts it to be printed with all the eight colors of Epson 4000. The manufacturer supplied RGB profiles are developed for a printing standard and hence matches the press sheet (the press is set to SWOP standards). Epson and other inkjet manufacturers provide a number of ICC profiles (RGB) for the different types of inkjet paper (like semigloss, semi matte, archival matte).

Figure 16 shows the workflow that was used for Model 5. The printer profile supplied by the inkjet or paper manufacturer was used (e.g., Epson4000_Proof-SemiMatte_PK.icc). In this model, the combined one-bits are not color managed for the press and inkjet printer in separate steps. The print dialog in Photoshop allows only one profile to be included at the time of printing. The use of an inkjet

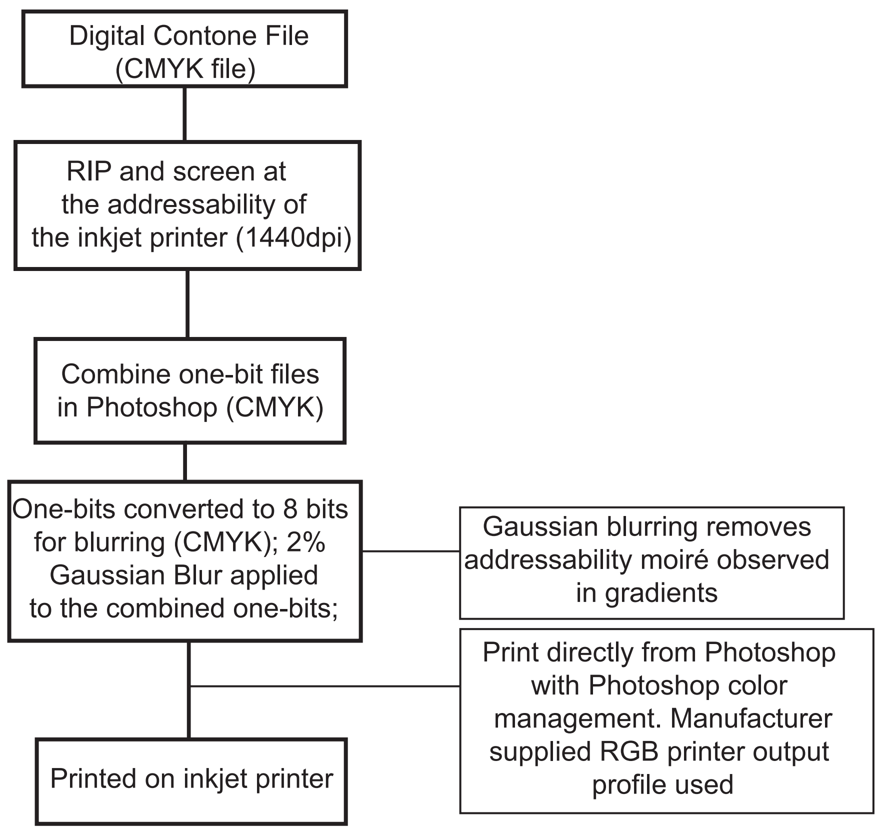


Figure 16: Model 5 Optimized Workflow

printer profile at this stage resulted in accurate ink limiting and color management. Ink limiting is a feature of the print driver that limits the amount of ink laid on the substrate. If a CMYK profile were used at this print dialog, the printer would not recognize the ink limiting parameters. Thus for efficient color management the profiles inside a printer driver had to be used. The user cannot create a printer profile for an inkjet printer using conventional methods. Therefore the profiles supplied in the print driver by the inkjet manufacturer were used. These profiles were made to a printing standard such as SWOP (Specifications Web Offset Publications) and were hence preferred. This will give a first approximation of color match if the press conforms to the same standards.

Summary of Models

Model 1 was an adaptation of the patent described in the Methodology. Model 1 proved to be too complex to implement and thus Model 2, that used contone files for input was developed. Model 2 evolved into Model 3 with better color management and RIP settings. Model 4 was developed to correct for the moirés that were observed in the gradients of the prints of Model 3. Gaussian blurring was used in Model 4 to correct for the residual moiré observed in the inkjet prints. Model 5 included color management in Photoshop's print dialog after combining the separations RIPped at 1440 spi and combining them. Model 5 yielded the best results of all the models proposed and tested in this thesis.

Survey of Inkjet Proofs

Moiré is a visual phenomenon and it is not possible to quantify the moiré observed in halftone patterns. Hence a survey was designed to evaluate the similarity of the proof moiré to the press sheet.

The proof produced by the Models 4 and 5 were presented before a group of observes for visual evaluation of moirés. The participants of this survey were screened for color blindness using the Ishihara's tests for color blindness. All the participants subjected to the test passed the screening. In some cases of moiré the patters are identified by the difference in color, hence making it important that the participants have good color vision. The proof was shown along with the Approval simulated press sheet and the participants were asked to look for similarities in the moiré pattern. Participants of this survey were mostly students from the Print and Photo Schools at RIT.

Chapter 5

Results

Proofs generated using Model 4 and 5 were compared qualitatively and quantitatively with the Approval simulated press sheet. These proofs were also benchmarked against commercially available halftone inkjet proofing solutions denoted as Product A and B.

Qualitative Comparison

A Survey was conducted, where the participants compared the contrast resolution targets and the pictorial images of the proof and press sheet. The participants awarded a ‘Pass’ or a ‘Fail’ to the images based on the similarity of moiré pattern observed. An overall ranking of 1 to 5 with 5 being accurate moiré simulation was also included in the survey. This enabled the participant to give an overall ranking of the proof as an indicator of moiré. An evaluation method similar to the Paired Comparison model described by Prof. Robert Chung was used (Chung, 2007).

Survey Results

For the survey, proofs created using Models 4 and 5 were compared individually against the Approval sheet. Some of the participants noted that the inkjet prints showed banding in the speaker image and produced moiré patterns not seen in the press sheet in the ‘Franz & Arvind’ image. Those verdicts are marked with an asterisk (*) sign in Table 1.

Table 1: Results of the Survey to test moiré

Observer	Sample A - Color managed - Model 4				Sample B - Color managed - Model 5			
	Contrast - Resolution	Franz & Arvind	Speaker	Overall	Contrast - Resolution	Franz & Arvind	Speaker	Overall
1	Pass	Pass*	Fail	**3**	Pass	Pass*	Pass	**4**
2	Pass	Fail	Fail	**3**	Pass	Pass	Pass	**5**
3	Pass	Pass*	Pass	**4**	Pass	Pass	Pass	**5**
4	Pass	Pass	Fail	**4**	Pass	Pass	Pass	**5**
5	Pass	Pass	Fail	**4**	Pass	Pass	Pass	**5**
6	Pass	Fail	Pass	**2**	Pass	Pass	Pass	**4**
7	Pass	Fail	Pass	**3**	Pass	Pass	Pass	**4**
8	Pass	Pass*	Pass	**4**	Pass	Pass	Pass	**5**
9	Pass	Pass*	Pass	**4**	Pass	Pass	Pass	**5**
10	Pass	Pass*	Pass	**4**	Pass	Pass	Pass	**5**
11	Pass	Pass*	Pass	**4**	Pass	Pass	Pass	**5**
	Total number of Passes 23 Total number of Fails 7 **Average Rank 3.5**				Total number of Passes 30 Total number of Fails 0 **Average Rank 4.7**			
Pass are the entries where the observers saw additional or more prominent moirés in inkjet prints than Approval.*								

Model 4, where the contone file was color managed before proofing, shows instances where some participants did not observe a similarity in the moiré pattern. This can be attributed to the fact that color management changed the values of the colors and affected the magnitude (strength) of moirés. This explains why other viewers could see the moiré pattern in the sample from Model 4.

All participants observed a similar moiré pattern in the three sets of images created using Model 5. Some participants commented on the difference in contrast and sharpness between the press sheet and the inkjet proof. The participants were also asked to rank the overall moiré match of the sample on a scale of 1 to 5, 5 being a perfect match. The average of the rank values of Models 4 and 5 were calculated to be 3.5 and 4.7 respectively. Also the moiré match in Model 5 was 100%, as per the survey results. The participants observed a similar moiré pattern in all instances with this proof. This clearly indicates that the participants prefer Model 5, which matches the press sheet accurately in terms of moiré. A t-Test was performed for the overall rank awarded to the models by the participants of this survey. The t-Test assesses whether the means of two groups are statistically different from each other. This analysis is appropriate when means of two groups are compared.

Mean of Model 4	= 3.55
Mean of Model 5	= 4.73
Standard Deviation of Model 4	= 0.69
Standard Deviation of Model 5	= 0.47
Mean of Model 4 – Model 5	= -1.18

95% confidence interval of this difference: From -1.70 to -0.66.

The confidence interval indicates (with a confidence of 95%) the range that the true difference between the mean of Method 4 and Method 5. Since this range does not include a value of zero, the observed difference is significant.

The calculated probability that this difference could occur by chance is less than .0001 which is very low. This is another indication that the observed difference between the two methods is significant.

Quantitative Comparison

Because of the poor results of Model 4, it was not tested for ΔE with the press sheet. The proofs from Model 5 match the press sheets visually. As a part of the Quantitative analysis the color gamuts of Model 5 and press were compared. A significant difference was observed in the gamut comparison.

The wireframe in Figure 17 represents the gamut of the press and the smooth rendering represents the gamut of Model 5. There was a considerable difference in the gamut towards black. This was researched extensively and the following conclusions were reached:

Gaussian blurring of the 1-bit files accounts for the loss of some color. There was a clear difference in the contrast and saturation of the prints with and without

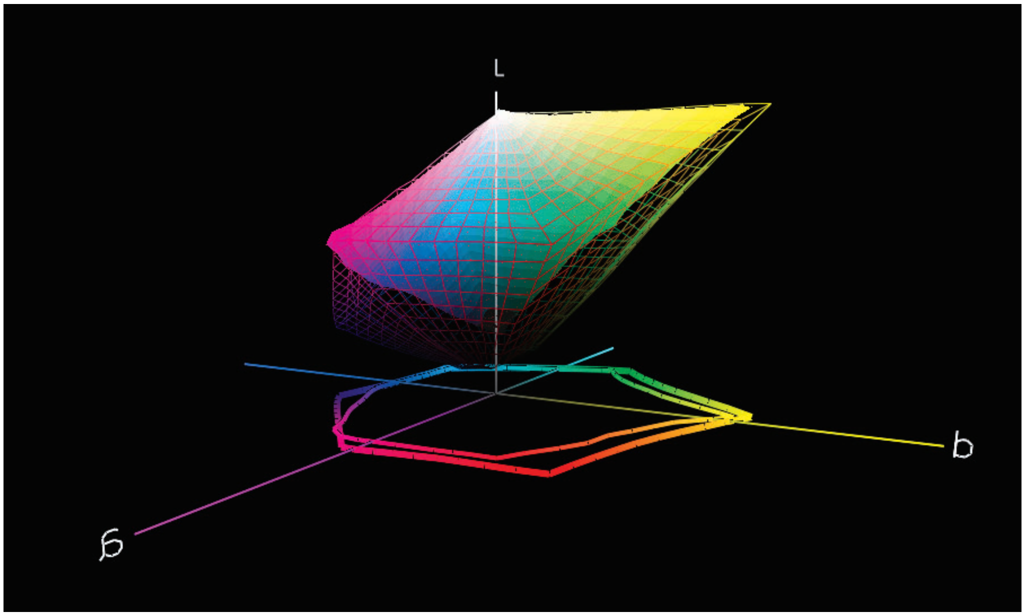


Figure 17: Gamut of Press (smooth) and Model 5 (Wireframe)

blurring. Though this difference was visible, it cannot account for the difference seen in Figure 17.

The inkjet printer used has a print driver that internally makes use of an RGB based system to parse the colors to all the eight colors of Epson 4000. The printer requires the input files to be converted to CIELAB color space. This requires color management using a manufacturer supplied ICC profile at the time of printing. The gamut of these ICC profiles is significantly larger than that of the press. The color conversions that happen at the printer before printing are not known. This could account for some difference in gamut. The interpretation of an RGB profile at the printer could be a topic of further research.

The Cumulative Relative Frequency (CRF) curve of the IT8 7.4 charts indicates a considerable difference between Model 5 and the press sheet. To display the results, a CRF curve is used which is based on the CumSum model developed by Mike Rodriguez of R.R. Donnelley. This curve sorts the readings based on the ranking and gives a percentile distribution of the results (Bartels & Fisch, 1999).

The CRF curve displays the cumulative relative frequency distribution of the ∆E of a measured test form. The 90% frequency means that 90% of the patches mea-

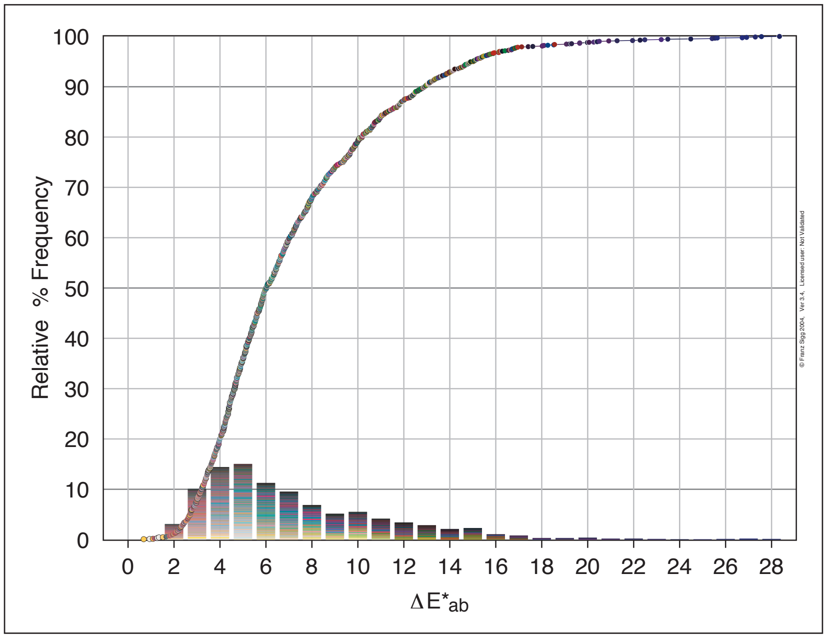


Figure 18: CRF curve of ∆E between Press and Model 5

sured fall below the corresponding ∆E in the plot. Figure 18 shows the CRF curve of Model 5 and the press (Kodak Approval).

The ∆E differences are bigger than desired, however, perceptually the prints actually match quite well.

The model proposed in this thesis matches the press sheet accurately in terms of moiré. The color match was within acceptable visual limits for the test case but would require special profiles to work with different paper types. This model does not require any additional software other than a RIP, Adobe Acrobat and Photoshop. The color management in Model 5 includes an RGB profile for output and does not correct for the profile of the press and the inkjet printer in separate steps. The print dialog allows the use of one profile at the time of printing and an RGB profile supplied for the paper type is used here. The use of the RGB profile is an approximation and presents the user with very limited options.

Benchmarking

In this section the proofs produced by Model 5 are compared to those produced using commercial software solutions. To maintain confidentiality the software used will be referred to as Product A and Product B. The software was set up at the Color Measuring Lab in the School of Print Media at RIT with help from the technical support personnel of the respective companies.

Product A

This software makes use of 1-bit files as the input. The software works well with both 2400 and 1440 spi. There is an optimization routine where a test target is printed and measured iteratively. The software uses proprietary color management algorithms to make color adjustments based on the readings. The initial proofs before the optimization did not match the press sheet. After the optimization process, the average ΔE of the printed target was reported by the software to be 2.22 with a peak ΔE of 8.64.

This software was tested for an extreme case: match the press sheet that was yellowish (b* value of 3). The difference in paper white was not fully rectified by the optimization routine. An IT8.7 test target was printed and measured, and the measurements were compared to a similar print made by Approval to obtain the results shown in Figure 19.

When used to make relative colorimetric proofs, using SWOP as a reference, then the software could proof with a ΔE of less than 1.

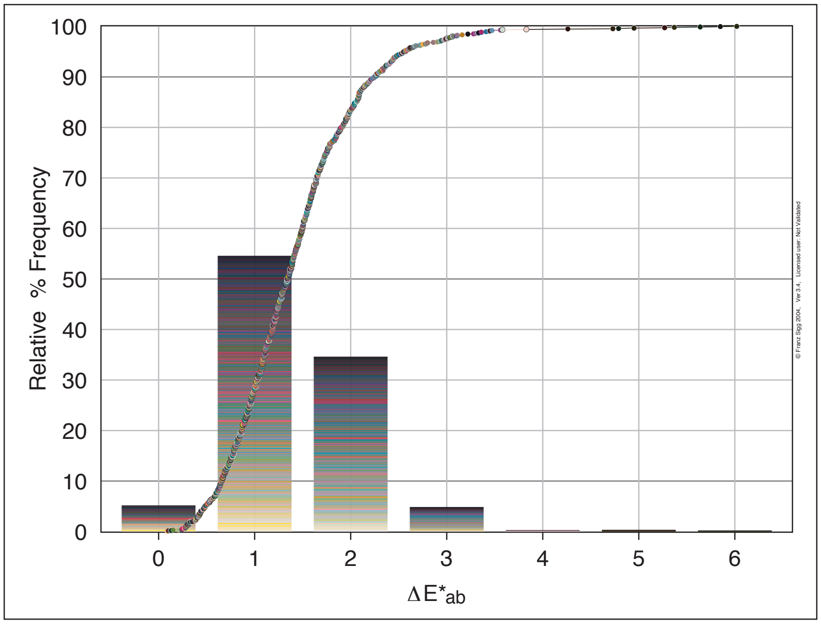


Figure 19: CRF curve of ΔE between Press and Product A

Product B

Product B is very similar to Product A, in features and operation. Both software products make use of a proprietary optimization model. And both were setup to proof a different white point. The CRF curve in Figure 20 indicates that

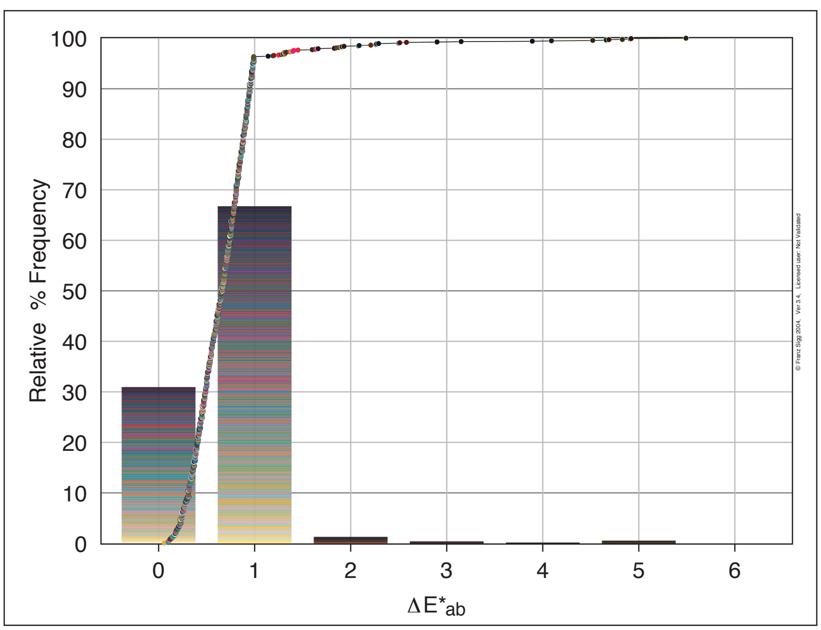


Figure 20: CRF curve of ΔE between Press and Product B

for Product B, most of the patches lie within 1 ΔE. This was a very faithful color reproduction. The optimization in this software was found to be superior to product A. The optimization process brought down the average ΔE to 0.67. The simulation of white point was very close to the target white point.

Both of these software products match the press sheet closely in terms of color. Some of the test images did not show an exact moiré match. This could be attributed to the fact that these software products make use of proprietary color management and use a de-screening step to prepare the files for the inkjet printer. These software products require a person skilled in color management and proficient in the software to set up. Also these software products are expensive, and not easily affordable for an individual or a startup printing press.

Chapter 6

Conclusions

The objective of this research was to use inkjet technology for producing proofs matching Kodak Approval proofs in terms of color, screening, and moiré. Model 5 proposed in this thesis yield proofs that visually match the press in color and moiré.

Inkjet printers have a lower addressability than the one used for offset presses. This results in a difference in prints produced using these two processes. To generate halftone inkjet proofs that match the press in terms of moiré pattern, the digital file had to be specially processed to compensate for the difference in addressability of the two output systems.

Several models to make halftone proofs have been proposed and tested, but only Model 5 produced proofs that visually matched the press sheet closely in terms of color and moiré. In this workflow, color management was introduced by using an RGB profile in Photoshop's print dialog. The RGB profile chosen was the profile supplied by the inkjet manufacturer for the substrate (e.g., Epson4000_Semimatte.icc) used in proofing. The visual match of the color can be adjusted by changing the printer profile. Manual adjustments at the printer driver (curves, color corrections) will not have a linear effect on the file as the file goes through an ICC color management process just before printing.

A survey where the participants compared the moiré patterns of the inkjet proofs with the moirés of the Approval simulated press sheet was conducted. All the participants found similar moiré patterns in the inkjet proof made using

Model 5. When asked to rank the inkjet proof in terms of moiré match, the participants awarded 94% (on an average) to the inkjet proofs produced using Model 5. However the color match was not within acceptable limits both in the case of the ΔEs of an IT8 target with that of the press sheet and in the comparison of the color gamuts. These differences are attributed to the limited color management that could be used in the workflow of this system.

Limitations of Model 5

Model 5 comes with a few limitations. The first and the most important limitation was the paper that was used for proofing. An inkjet paper that has been certified by GRACoL and Fogra to match the CIELAB specifications of ISO-12647 7, differs greatly in terms of amount of Optical Brightening Agent (OBA). This causes the inkjet proof to be highly metameric and matched the press sheet only under a specific lighting condition (D50 in our test case). The ISO document does not specify OBA requirements for proofing papers. With Approval and other traditional film-based proofers, the same paper on which the job is printed is also used for proofing. In the case of inkjet printers, specially coated papers are needed. Regular press papers cannot be used for inkjet printers and vice versa. This presents the user with a problem. However there are quite a few different types of inkjet papers, some specifically made to match a particular press sheet.

To use this method, it is recommended that the user finds a paper that matches the press sheet closely for the inkjet printer. This way, no white point correction is needed. For this research, Epson Proofing Paper Semi-matte was used. This inkjet paper is manufactured without any OBA.

The color management that could be included in the proposed model was very limited because the printer requires an RGB profile at the print dialog. The printer has eight colors and it needs an RGB profile to include details about ink limiting. The use of CMYK profiles in this stage did not yield the expected results. This means that the user must choose the ICC profile provided by the manufacturer (Epson) for the substrate used for proofing (e.g., Epson4000_Semigloss.icc). This presents the user with very few options. The RGB profiles supplied by the manufacturer are few and they are developed to match a standard like SWOP. Proofing to a condition that is different from such a standard is not possible. The use of device link profiles might prove to be a solution for this problem. This was not tested in this thesis.

Proposed Model 5 did not involve any optimization of the printed colors. The commercial software products used for comparison, include an optimization procedure where a specified test form is printed and measured into the software. A correction profile, which has a look up table similar to the ICC profile, is created and used when printing to the inkjet printer. Programming such an optimization routine is complicated and requires advanced programming skills and understanding of the process. This could not easily be done by a normal user.

This optimization is critical when the paper white of the press sheet is to be simulated in the inkjet proof. For Model 5, by using paper that matches the press sheet closely, there is no need to simulate the press paper white. Relative colorimetric rendering can be used in this case to print just the images at the right color. The use of the manufacturer supplied RGB profile when printing from Photoshop also gives the user very limited options. Ideally the file would have to be color managed for the press and the inkjet printer in separate steps. This is not possible in the Print Dialog of Photoshop. This limited color management gives the user a first approximation of a color match. The model proposed does not allow the user to improve the color match that is obtained.

Because of the limitations of the color management that was included in the workflow, the color match that was obtained with Model 5 was not within acceptable limits when only measurements are considered. However, a visual comparison in terms of color and moiré was satisfactory, and could be acceptable for many applications. The researcher would recommend this model for halftone proofing if the main purpose of the inkjet proof is to predict press moiré.

Recommendations for further research

The print dialog in Photoshop allows the use of one profile at the time of printing. Link profiles could be created and used at this stage. This was not tested in this research.

The effects of super cell screening and other proprietary screening methods on moiré and the gray level reproduction could be a topic for further research.

Another recommendation would be to study the moiré patterns that appear when spot colors are used and the simulation of the same in inkjet printers.

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